Lidar Measurements of Smoke from Western Wildfires

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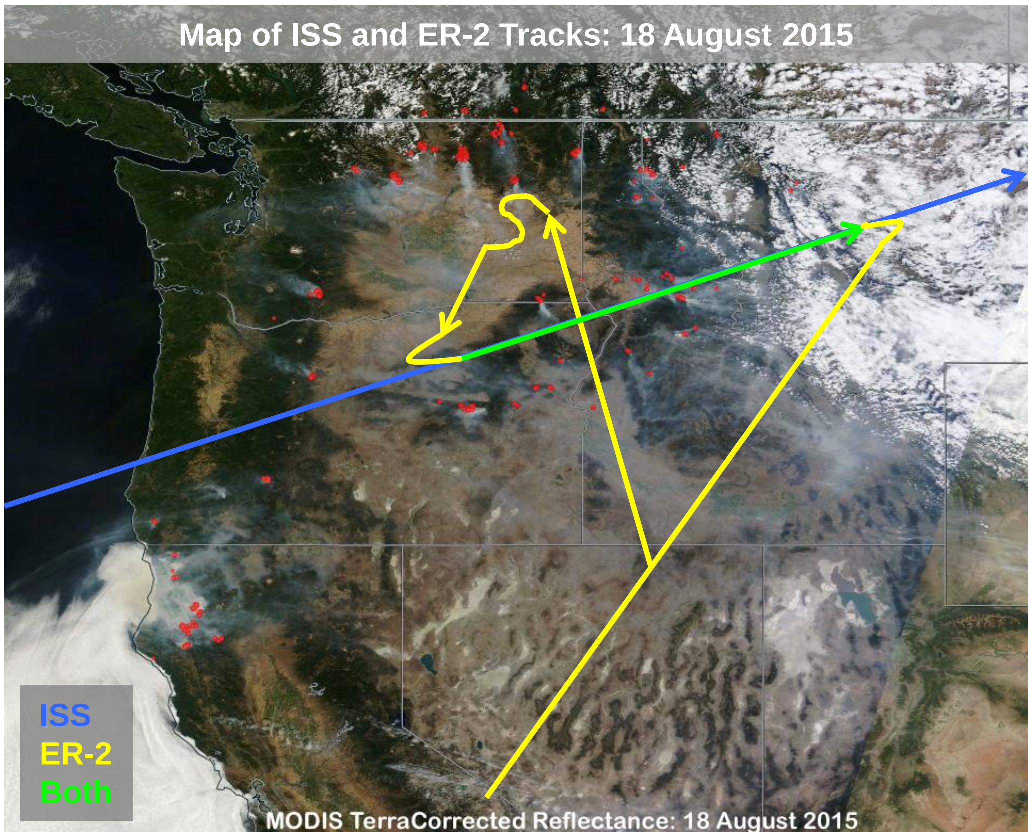
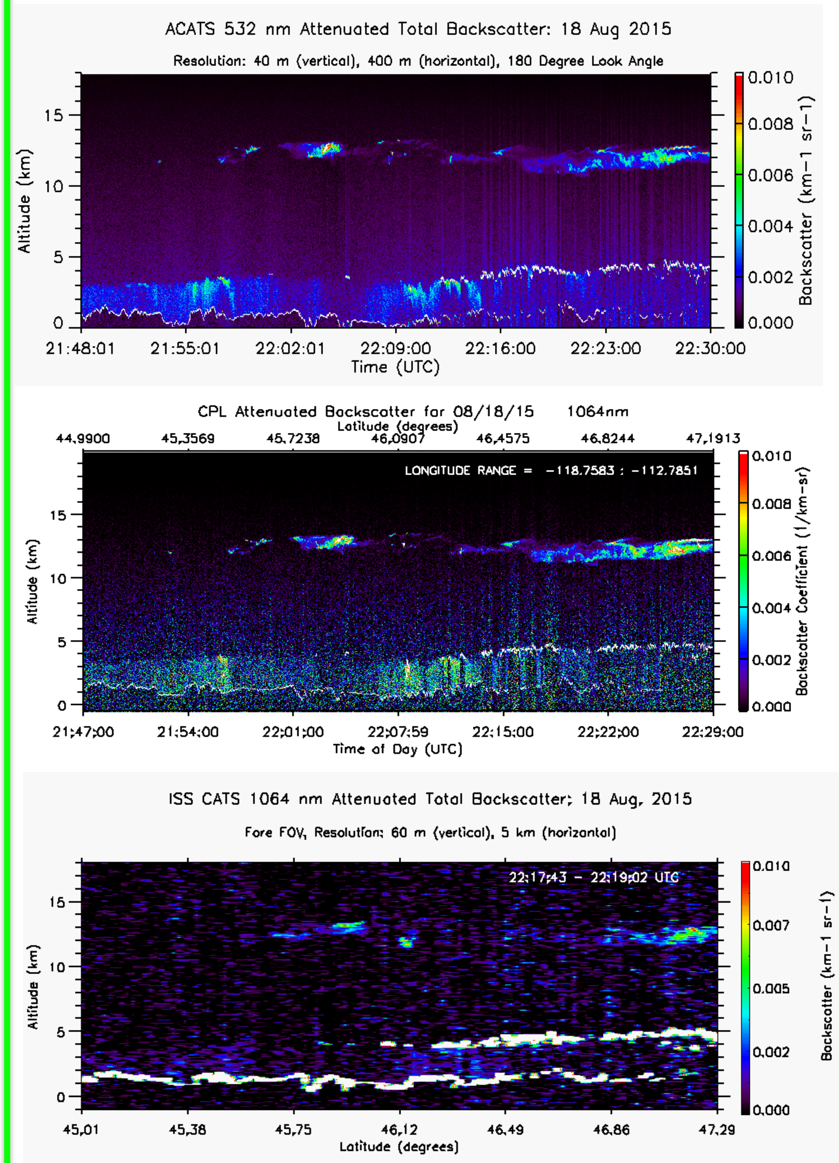
Coincident **backscatter** measurements of **smoke from wildfires** in the Pacific Northwest from **ACATS** (top panel) and **CPL** (middle) on board the NASA ER-2 are used to **validate** measurements from **CATS** (bottom) located on the ISS.



Lidar Vertical Cross Sections



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References:
Yorks, J. E., M. McGill, V. S. Scott, A. Kupchock, S. Wake, D. Hlavka, W. Hart, P. Selmer (2014), The Airborne Cloud-Aerosol Transport System: Overview and Description of the Instrument and Retrieval Algorithms, *J. Atmos. Oceanic Technol*., **31**, 2482–2497, doi:10.1175/JTECH-D-14-00044.1.

McGill, M. J., J E. Yorks, V. S. Scott, A. W. Kupchock, P. A. Selmer (2015), The Cloud-Aerosol Transport System (CATS): a technology demonstration on the International Space Station. Proc. SPIE 9612, Lidar Remote Sensing for Environmental Monitoring XV, 96120A. doi:10.1117/12.2190841.

Data Sources: Cloud Physics Lidar (CPL) and Airborne Cloud-Aerosol Transport System (ACATS) backscatter data was collected during the CALIPSO-CATS Airborne Validation Experiment (CCAVE) in August 2015 in Palmdale, CA. The Cloud-Aerosol Transport System (CATS) backscatter data is collected in near real time and products can be found at cats.gsfc.nasa.gov.

Technical Description of Figures:
A map of the ISS and ER-2 tracks from 18 August, 2015 shows that both platforms flew over smoke from wildfires in the Pacific Northwest region of the U.S. The CPL and ACATS instruments on board the ER-2 (track in yellow) were used to validate the CATS instrument located on the ISS (track in blue). The ER-2 flight, planned as part of CCAVE, targeted the ISS track for a segment of coincident data (green) over smoke and cirrus clouds.
Lidar cross-sections of attenuated total backscatter from 18 August, 2015 during the coincident segment (green in left image) for the ACATS (top panel), CPL (middle) and CATS (bottom) instruments show smoke from wildfires below 4 km, water clouds at the top of the smoke layer (4 km), and thin cirrus clouds between 11 and 13 km. ACATS is a high spectral resolution lidar (HSRL) that operates only at the 532 nm wavelength, shown in the top panel. CPL operates at multiple wavelengths (355, 532, 1064 nm) and is the primary cirrus cloud validation tool for space-based lidar systems. CATS has been operating from the ISS since Feb. 2015 at both 532 and 1064 nm, with the latter showing more robust signal. Thus, the CPL (middle) and CATS (bottom) 1064 nm backscatter are shown here. The backscatter data from all three instruments agree well, however the space-based nature of CATS and daytime conditions prevent CATS from detecting the very thin smoke and cirrus layers observed in the CPL and ACATS data (Note, CATS would see these features at night).

Scientific significance, societal relevance, and relationships to future missions: Obtaining an accurate assessment of cloud and aerosol properties and their transport remain a major challenge in understanding and predicting the climate system. The CATS, CPL, and ACATS data products have a large range of applications to significant climate system issues, such as examining cirrus optical properties, assessing dust and smoke transport, and investigating cloud-aerosol interactions. Therefore, the validation of the CATS data products is crucial in quantifying uncertainties and detecting biases in the retrievals and should in turn strengthen the results of future studies using CATS data. In additional, ACATS advances component technologies and algorithm development by producing an airborne instrument applicable to prototyping an HSRL for NASA's Aerosols-Clouds-Ecosystems (ACE) mission.

A new tool for Earth Observations Using Small Satellites

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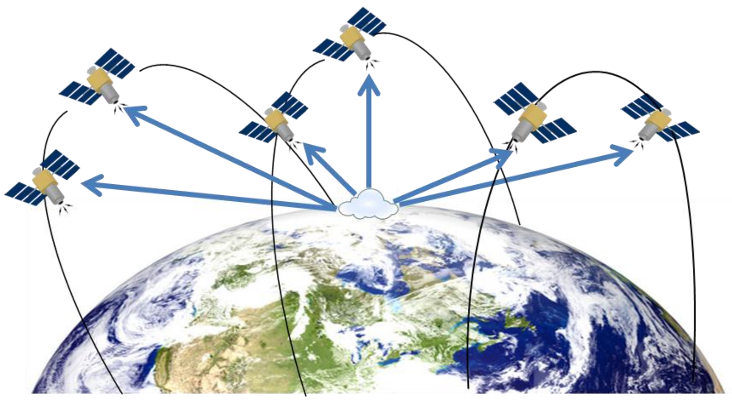
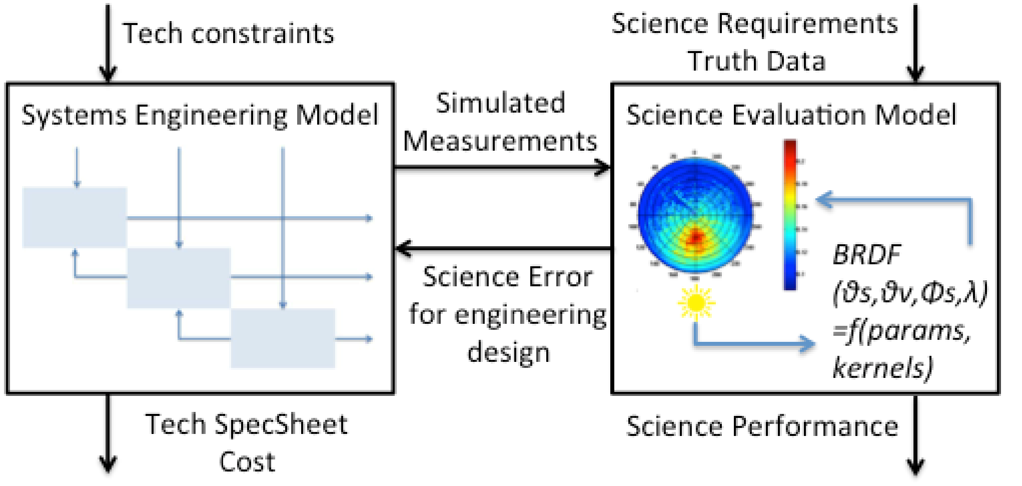
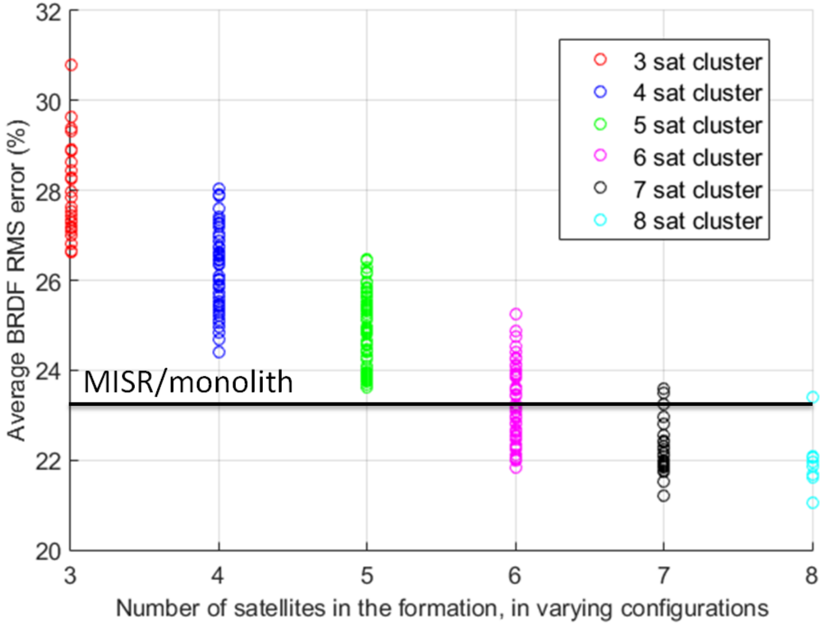
a) Small Sat Formation



b) OSSE-driven Modeling Framework



c) Results



Our new software system allows investigators to assess the value of small satellites in Earth observations. We show that using a formation of a few small satellites, optimally arranged and maintained, minimizes angular sampling gaps and yields better BRDFs (bidirectional reflectance-distribution functions)

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References:

Nag, Sreeja, Charles K. Gatebe, and Olivier de Weck. “Observing System Simulations for Small Satellite Formations Estimating Bidirectional Reflectance.” *International Journal of Applied Earth Observation and Geoinformation* 43 (2015), 102-118, doi:10.1016/j.jag.2015.04.022.
Sreeja Nag, “Design and Evaluation of Distributed Spacecraft Missions for Multi-Angular Earth Observation”, PhD thesis, MIT 2015.
The authors acknowledge Rajesh Poudyal for extracting and post-processing the BRDF data, Warren Wiscombe for his contribution to Leonardo-BRDF concept, Ralph Kahn, David Miller, Kerri Cahoy and Alexei Lyapustin for their valuable ideas toward making this study better.

Data Sources: Cloud Absorption Radiometer (CAR) BRDF data from the following NASA campaigns: ARCTAS 2008, CLAMS 2001, SAFARI 2000, ECO-3D 2011, CLASIC 2007, and INTEX-B 2006. Global Land Cover Map from Global Land Cover Facility (GLCF) driven by MODIS, Two-Line elements of MISR from the AGI (Analytical Graphics Incorporated) STK (Satellite Tool Kit) database.

Technical Description of Figures:

Graphic (a): A maintainable formation or constellation of small satellites proposed to improve near-simultaneous angular sampling . The formation can make multi-spectral and multi-angle contemporaneous measurements of a ground target as it passes overhead by using narrow field of view (NFOV) instruments in controlled formation flight.

Graphic (b): The framework to design small satellite formations pairs systems engineering with science evaluation. The systems engineering module is based on model-based systems engineering (MBSE). It generates potential formation designs, assesses technology feasibility, calculates high-level cost and assumes continuous measurements as the formation flies over the globe. The science evaluation module, also called the OSSE (observing system simulation experiment), evaluates the performance metrics for each feasible formation design. Performance metrics assess performance in angular, spectral, spatial and temporal domains. For example, the angular error terms are calculated as the difference between simulated errors and “truth” data such as NASA CAR BRDF or synthetic data. The coupled model outputs metrics and their inherent trade-offs for every instant in the simulation, and the simulation repeats this process over multiple orbits spanning the mission lifetime. The model’s utility is to identify formation designs that maximize science performance and minimize cost among those architectures which fit the input constraints.

Graphic (c): BRDF estimation error (RMS), averaged over time, for increasing satellite number at a 650 km, 51.6° orbit for a formation. The error is represented as a percentage of the CAR reference data. Each symbol represents a maintainable formation configuration in different planes and positioning within the plane. The horizontal black line represents MISR’s estimation error, calculated using the same simplified OSSE used for formation evaluation. Due to economies of scale and other learning curve benefits, the cost of building multiple satellites is less than linear, therefore the performance to cost curve will be steeper than the one shown.

Scientific significance, societal relevance, and relationships to future missions: Our new software system for OSSEs will allow investigators to quantitatively assess the value of the next-generation observing systems, compare with existing operational systems in a controlled software environment, and determine if there is value added in the form of improved satellite retrieved products. We demonstrate that a few small satellites can provide improved measurements compared to monoliths.